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INTRODUCTION

STEM and teacher education policy: global significance and local interactions in Mexico and the UK

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Science, Technology, Engineering and Maths (STEM) education has attracted increasing attention in the last two decades, partly because the development of STEM itself, particularly in terms of Science and Technology, is often associated with national economic growth and human skills development. There is an assumed, generic link between STEM and the fostering of productivity, technological innovation and the growth of national economies and their GDP (Freeman, Marginson, and Tytler 2015). STEM education is thus becoming an increasingly significant focus for governments and for educational policy worldwide, with a high proportion of educational research and practice funding being earmarked to develop STEM. Despite the predominance of the claim that STEM education is integral to economic futures, there are critical perspectives on this economic argument in support of STEM education (Roschelle et al. 2011). Some research evidence reveals that overall educational quality is a more potent influence on economic outcomes (Hanushek and Woessmann 2012) and that innovative curricula and pedagogies are what is needed (Marginson et al. 2013). A number of large funded research projects over the last decade such as epiSTEMe in England (Cambridge University) have aimed to assess the impact of pedagogic change in STEM subjects or to intervene in the delivery of STEM as in the case of the STEM for Diversity project (see Hetherington and Wegerif this volume). Other researchers claim that in many contexts education is not the predominant determining factor in economic growth and the impact of education on the economy is bounded by scope and time (Bevan 2011; Brown, Lauder, and Ashton 2012).

It is against this background that STEM education has become a piece in the complex jigsaw of globalisation. Globalisation itself is variously cast as a panacea for inequality (Zeidler 2016) and is also seen to be propagating as many inequalities as it is solving (Marginson et al. 2013; Stromquist and Monkman 2000). STEM education is similarly contradictory, being seen as a universal driving force for international development, but also remaining at the complex nexus

of social, political and cultural inequalities with issues of gender and the education of indigenous populations being of particular concern. A recent UNESCO announcement noted the centrality of science education in the global sustainable development agenda, with the head of the United Nations' educational and scientific agency emphasising the importance of science centres and museums in developing skills and capacities, particularly for girls and marginalised communities (Alexovich 2016). Despite the evident significance of STEM, women and girls continue to be under-represented in fast-growing STEM jobs and with the increase in 'disruptive technologies', including robots and artificial intelligence, it will be marginalised groups that will be most affected (Amerasinghe 2016). Not only do women, diverse ethnicities and other marginalised groups continue to be under-represented in STEM sectors, but their concentration in low skilled employment is a vicious circle in the reproduction of social inequalities and disadvantage (Kersley and Shaheen 2014). Expanding engagement and emphasis on STEM education will be critical if there are to be improvements in the quality of work for under-represented groups and communities.

This special issue focuses on reconceptualising the teaching of STEM education through dialogue and transformative learning, presenting examples of research from Mexico and the UK. It centres on research which introduces a critical approach to pedagogies in the teaching of STEM, where in the past there has been an over emphasis on content and a more disciplinary perspective on science. It is important to note that what is meant or understood by the concept of STEM itself is not always clear; for some, STEM is synonymous with Science and for others it is interchangeable with Technology (Akgun 2013). The term STEM is used in many different ways and the papers in this special issue underline the fact that STEM, both as a concept and as an educational issue is strongly embedded in its social, cultural and political context (Khishfe et al 2017).

The research in this special issue considers critical and dialogic approaches to teacher education for STEM subjects in Mexico and the UK and emphasises the crucial role that teachers play in improving life chances for marginalised young people and their communities. STEM education may be held up as a means of improving a country's GDP but if taught through dialogic and transformative pedagogies it can enable teachers to empower students to improve their own lives.

This special issue draws on research from a British Council funded project which linked the conceptual areas of educational dialogue and transformative learning in the context of STEM education in Mexico and the UK (Fernández-Cárdenas and Montgomery 2015, 2016). There has been considerable research work developed separately in educational dialogue and in transformative learning, but these two areas have not been brought together in the context of the study of STEM subjects in teacher education nor have these linked ideas been applied in Mexico and the UK. The collaboration between these two countries is timely and comes at a time when Mexico is developing and emerging as a key global economic and political nation. The special issue compiles a collection of articles focusing on educating teachers of STEM in an international comparative perspective, reflecting on the current state of teacher education in STEM subjects in Mexico and the UK and examining the sorts of innovations and new approaches that are being introduced in the two countries, particularly in dialogic teaching and transformative learning. There is also an emphasis here on how dialogic and transformative approaches in STEM education can improve opportunities for groups excluded or marginalised in STEM education through the refocusing of teacher education for STEM. This introductory paper aims to set the scene for the papers which follow by considering the policy context of teacher education in both Mexico and the UK and analysing the key themes that will be drawn out in this issue.

STEM and teacher education policy in England and Mexico

As discussed above, the grand narratives outlining the benefits of STEM and STEM education in improving national, industrial and community prosperity are prevalent but this discourse is not accompanied by a strong discourse in policy for education. In the UK, there appears to be a lack of systematic actions in relation to the policy on how teachers should be educated to engage with the fast-moving world of STEM. According to a study carried out by the Council for Science and Technology (2000) “there was a concern among science teachers about how they could develop personally and professionally throughout their careers.

Teachers relied on local networks of informal contacts, either in-school or between schools, and a number of school-based training days which, because of their whole-school nature, rarely dealt with subject-specific issues” (Tomei, Dillon, and Dawson 2014, 173; see also Dillon et al. 2000)

This indicates that teachers feel a lack of guidance and direction from policy for STEM education and some of the papers in this special issue explore both the effects of this (Aslam, Adefila, and Bagiya this volume) and some possible innovative approaches to addressing this (Watermeyer and Montgomery this volume; Fernández Limón, Fernández-Cárdenas, and Gómez Galindo this volume). In the current education policy in the UK, reference to STEM education is located in the Department for Business, Energy and Industrial Strategy (BEIS), the department that recently replaced the UK Department for Business Innovation and Skills. A policy paper was published in 2012 and updated in May 2015 entitled ‘Public understanding of Science and Engineering’ and the paper notes:

“Science and research are major contributors to the prosperity of the UK. For our prosperity to continue, the government believes we need high levels of skills in science, technology,

engineering and maths (STEM), and citizens that value them” (Department for Business, Innovation and Skills 2015).

In terms of the ways that this policy is enacted, the policy paper notes that the approach to promoting STEM will be to engage the public in science and engineering through the British Science Festival and the National Science and Engineering Week and events that promote science and raise the public’s awareness of science issues (see Watermeyer and Montgomery this volume). The approach also involves funding of 4 independent national academies which are the Royal Society; the British Academy; the Royal Academy of Engineering and the Academy of Medical Sciences. The encouragement of science in schools and the funding of programmes and events that inspire students to study STEM subjects is also mentioned as a key priority. Despite this foregrounding of the significance of STEM and engaging with education, there is a notable absence of links with the Department of Education or any links with teacher education policy. An initial analysis of the policies of the UK Department of Education published since 2011 show that the strategy has been segmented into regions and it was only possible to locate specific recommendations from Northern Ireland. These recommendations are centred on a) coordinating business links so that the demand for STEM graduates increases, b) managing STEM sector attractiveness by working with museums and schools in innovative ways, and c) facilitating CPD development, contextualising educational activities to meet the demands of communities (Department of Education 2011). Given this segmented strategy in STEM education policy in the UK, it is easy to see how challenges in translating this policy into teacher education for STEM could be generated. As far as policy on teacher education in England is concerned, the most recent policy guidance on teacher education was the Carter Review which appeared in July 2016, giving the framework for core content for Initial Teacher Training (ITT) but there is a notable absence here on guidance for

specific subjects such as STEM (Carter 2015). Furthermore, there is no guidance in this policy on the enactment of subject specific pedagogy for any particular disciplines or subjects resulting in a silence on more complex interdisciplinary pedagogy for STEM education and its implications for teacher education. In teacher education programmes in England, guidance on STEM is compartmentalised into single disciplines such as Science and Maths, leaving an interdisciplinary approach to remain as an ideal. In 2013 the UK government moved towards more focus on school-based teacher training and this complicates the context considerably, meaning that the role that Higher Education could play in the debate around STEM education and its implications for teacher education is also increasingly limited. The segmented policy on STEM for teacher education is thus even more problematic and results in greater fragmentation of approaches and understandings.

Notwithstanding the apparent gaps in education policy and teacher education policy in England, this does not mean that there are no initiatives around public engagement with STEM and STEM education. There are extensive STEM networks and STEM activities in communities, museums and informal science centres across the UK which are aiming to encourage engagement with STEM. The organisation STEM Ambassadors ('STEM Ambassadors STEM' 2017) is an example of such an organisation and is a government funded group which organises events, an ambassadors' scheme, funds after school clubs and offers resources and CPD for teachers. The UK Department for Education and the Wellcome Trust support the National STEM Centre which runs a programme of CPD activities and has a strong resource collection in its e-library. Part of this collection relates to policy for teacher education ('STEM Education: National Policies and Reports' 2010) but much of this is out of date. The National STEM Learning Network ('Impact of the National STEM Learning Network' 2017) also provides a wide range of activities for students and teachers but it is not clear what policy priorities underpin these activities. Thus, despite the funding being given to

these sorts of activities which demonstrate the UK government's commitment to supporting the development of STEM education, there are tenuous links between these activities and teacher education. There may be informal links through schools outwards to these initiatives but in terms of educating teachers around how to engage well with these resources, there is a gap (see Aslam, Adefila, and Bagiya this volume).

An international comparison of the situation with policy on teacher education for STEM shows that there are similarities and differences in Mexico. Historically, science education in primary and secondary schools in Mexico has not been seen as a priority for national development. Spanish and Mathematics, as disciplinary fields, without an applied multidisciplinary approach (as is the case of STEM education), have been considered the most important subjects for developing competencies for successful careers and for solving problems in everyday life. Thus, little time is allowed for the teaching of science in basic education classrooms and CPD efforts have not focused sufficiently on realising the importance of science and STEM education for an economy based on applied research and innovation (Flores-Camacho 2012).

More recently, a new educational policy has been designed in Mexico (Secretaría de Educación Pública 2017) and this highlights the speed of the social and academic changes which have become part of our everyday lives in a globalised world. The policy stipulates that teachers should have the competencies to be able to solve problems derived from societal change, and to use these processes as exemplars to construct knowledge with their students. Teachers need to be capable of teaching complex curricular subjects to students and should also be able to promote their active engagement in the solution of the problems of their communities. In order to achieve these goals, teachers participate in a Continuous Professional Development scheme called 'Teacher's Professional Service' ('Servicio Profesional Docente'), which is aimed at the development of competencies through the

evaluation and the modelling of innovative educational practices through two different schemes. The first scheme draws on the offer of courses available at teacher training centres (Centro de Capacitación y Actualización de Maestros, CECAM) where a catalogue of CPD courses is offered for teachers in order to promote a situated, self-regulated learning, through collaboration and social participation. The second scheme takes place directly in schools, and is carried out through the cultivation of communities of practice where teachers engage in reflective experiences about their everyday life at school and the development of pedagogical practices (Posner 2004). Reflective practice is discussed as part of this CPD community and led by the head teacher in each educational setting. In general, the pedagogy which the Mexican government hope to implement as part of this new model draws on the use of real world problems to be addressed as part of the curriculum, relating disciplinary knowledge with the construction of situated solutions. However, these goals are far from what actually occurs in STEM education in Mexico; and policy is similarly unclear on teacher education with only very general statements presented to guide the educational Mexican system and an acknowledgment that it is difficult to keep pace with the speed of change:

‘the accelerated development of science and technology have had a profound impact in everyday life of the inhabitants of all countries on earth. This area of human knowledge has developed with great speed in contrast with what used to happen in previous periods with a more gradual rhythm of change’ (Secretaría de Educación Pública 2017, 129).

The most explicit policy relating to STEM and teacher education for STEM in Mexico is on technology education. Teachers are expected to master the use of ICT, and to incorporate digital open resources into their lessons. Also, training in robotics is being promoted through an initiative called ‘@prende 2.0’, which involves the equipment of 3000 special ICT rooms

in selected schools, with high speed internet, specialised robotics pieces organised in collections, and computational languages for programming solutions and building apps. This is a very recent initiative that has not been assessed yet, but resembles the goals of an emblematic educational programme called ‘Enciclomedia’, based on the massive set up of interactive whiteboards (IWBs) in schools across the nation. IWBs added a value to the educational process, but in a limited fashion determined by the pedagogical background and knowledge of each teacher (Fernández-Cárdenas and Silveyra-De La Garza 2010). Despite this, there is no single explicit reference to STEM in the policy documents produced by Secretary of Education in Mexico.

At a societal level, and as in the UK, several non-governmental organisations are working in favour of advancing the agenda on STEM Education in Mexico. For instance, Innovec (‘Innovec’ 2017) is a civil association aiming to advance research, innovation, and the development of strategies to improve the teaching of scientific activities in basic education for children and teenagers. It was originally funded by the Mexico-United States Association for Science and since 2002 it has been delivering CPD programs and workshops for pupils and teachers, as well as designing assessment practices looking at science as an inquiry-based endeavour which requires links with communities and academic bodies in universities and research institutes.

Similarly, ‘Programa Adopte un Talento’ (‘PAUTA’ 2017) is an association of scientists, pedagogues, educational psychologists, and teachers, who are devoted to offering seminars and workshops for pupils and teachers with the objective of developing STEM competencies. Pauta is based in 5 states in Mexico and is working as a non-profit organisation in underdeveloped settings, promoting socioeconomic development through the appropriation of scientific and technologic tools for solving problems emerging from the community and in close alliance with local schools.

Finally, as a third example of Mexican initiatives, ‘Sophie’ (‘Proyecto Pedagógico Sophie UNAM, Ciencia Para Niños y Jóvenes’ 2017) is a project which aims to introduce children and teenagers to science in the disciplines of Physics, Chemistry, Mathematics, and Biology, as well as promoting the development of intelligence, creativity, and critical thinking. Sophie is a UNESCO project led by the National Autonomous University of Mexico and uses experimentation and play to enhance curiosity and exploration, helping students to focus their attention in inquiry based activities.

All these initiatives have laudable missions in relation to helping young people and teachers to develop competencies in STEM subjects. However, it is problematic that these organisations are not linked to and do not receive sustainable support from the government, and they are also not articulated in government policy on teacher education for STEM. If STEM is going to make a societal change, it is necessary to increase the scale of the educational impact, growing from a selection of interesting cases and associations towards a wider ranging systemic effect.

Challenges of moving forward with teacher education for STEM

As indicated by the discussion above there are direct challenges posed by the structures and formats of teacher education in the area of STEM. A major challenge in STEM education in both Mexico and the UK is the quality of teachers, their engagement with innovative pedagogies for STEM and teachers’ own individual understandings and expertise in understandings of Science (see Watermeyer and Montgomery this volume; Fernández Limón, Fernández-Cárdenas, and Gómez Galindo this volume; Aslam, Adefila, and Bagiya this volume). Professionals with in-depth expertise in STEM subjects are tempted to follow careers in STEM itself and the status of the teaching profession in both countries discourages ‘real scientists’ from pursuing a career in teaching. In particular, away from the large cities,

in rural settings in Mexico teachers themselves are marginalised and it is striking to see that the majority of teachers come from lower socio-economic backgrounds and are not closely engaged or linked to communities of scientific education, and therefore have problems in catching up with dominant discourses of science (INEE 2015; Torres del Castillo 1998). In the UK, there are teacher shortages in most STEM subjects and even at ‘A Level’ (16-18 years) teachers are required to teach in disciplines that are not their own. In both Mexico and the UK, teacher education is perceived as a second-class option and society tends to see teachers as second-class professionals, especially in contrast to ‘real scientists’ (see Watermeyer and Montgomery this volume). Papers in this special suggest that the weak links between teacher education, science and the knowledge base of teachers are a crucial element in the continuing inequalities around STEM education (see Fernández Limón, Fernández-Cárdenas, and Gómez Galindo this volume; Watermeyer and Montgomery this volume). Given the difficulties in addressing the complex inequalities and marginalisation associated with the development of STEM, it appears that there are challenges in moving forward with exploiting the potential of the current interest and investment in STEM education. Much focus in regional economic development strategy aims to grow the scientific, engineering and manufacturing sectors rather than improving approaches to education. Alongside this there has been some significant infrastructure investment around sector development and 14-19 education and training but this has occurred in regional pockets in both the UK and Mexico. Emerging research from organisations (Pike et al. 2016) suggests more work needs to be done to ensure that investments benefit the most disadvantaged elements of local communities.

Dialogic and communitarian STEM education

This special issue aims to construct STEM education as dialogue embedded in both formal and non-formal communities and built on constructive partnerships between teacher educators,

alternative non-formal science education settings in the community and the more formal bastions of scientific research and knowledge in the university. In this model of communitarian STEM education, particular significance is placed on dialogic understandings, both in the context of community relations, but also in terms of the pedagogies employed in STEM in schools and universities. Bakhtinian dialogism encourages the analysis of patterns of teacher-student communication in naturalistic classroom settings (Skidmore and Murakami 2016; Hetherington and Wegerif, this volume) but this special issue calls for a broader understanding of dialogism that extends to interaction between teacher educators, teachers, community actors and more formal domains of knowledge in the university and society, promoting a Freirean style of communitarian dialogue as emancipation. Freire (1989) proposed that education should develop a critical consciousness in which teachers empower students to surface their personal understandings of their own learning experiences but this approach is rarely applied in STEM education. Dialogic teaching moves away from the privileging of one voice (a monologic space) where the dominant voice is usually the teacher, towards the development of a dialogic space in teaching where students and teachers interact around the curriculum (Cowie and Aalsvoort 2000; Hetherington and Wegerif this volume). In addition, studies in education following a dialogic perspective have highlighted the importance of language positioning in the context of the teaching relationship, as well as the ethics involved in a dialogic space in which two or more voices can express themselves without trying to silence each other (Bakhtin 2010, 1993; Reynaga-Peña et al. this volume; Castro Félix and Daniels this volume).

These dialogic transformative partnerships aim to move away from the conception of STEM as content towards the relocation of STEM in local settings. A crucial element of this is enabling teachers and teacher educators to understand their own role and the role of their own knowledge in STEM education, not as conveyors of knowledge but as dialogic partners in co-construction in the local community.

This special issue

This special issue aims to build an understanding of how dialogic approaches can be embedded in teacher education for STEM and how this can be more strongly embedded in local communities, engaging teachers with structures both within and outside of the classroom and school in order to develop a locally relevant dialogic pedagogy for STEM which could be more effective in addressing marginalisation.

The special issue opens with focus on teacher education for STEM in formal contexts, with a higher educational perspective on how communities of engineering and science teacher educators in university settings can transform their understandings of their own practice. Castro-Félix and Daniels offer a Vygotskian, socio-cultural account of how teacher support teams can improve university tutors' use of joint activities in order to make changes in their teaching and thus improve student performance. This paper shows how it is possible to use the affordances of dialogue within the boundaries of formal higher educational settings, constructing common goals that could bring about continuous improvement in teaching practices in STEM disciplines.

In the second paper in this collection we continue to consider teacher education for STEM in formal educational settings with a close-up view on teachers working with dialogic STEM in the classroom. Hetherington and Wegerif argue that science teacher education and professional development should pay more attention to the material-dialogic relationships in the learning that emerges in science classrooms. The paper suggests that it is crucial for trainee teachers to become competent in managing the materiality of classroom practice and that dialogic pedagogy could remain a theoretical concern if teachers fail to broaden their understanding of the complexities of the material in science. Hetherington and Wegerif's drawing together of a Bakhtinian dialogic pedagogy (Wegerif 2012) with Barad's material-discursive epistemology

is an innovative theoretical approach which could provide an important new way of constructing dialogic practices in STEM education.

In the third paper Reynaga-Peña et al. focus attention on the use of dialogue in inclusive practices, specifically centring on STEM education for visually impaired learners. The case study presented underlines the importance of teacher peer and self-reflection around inclusion in science education, transforming and sensitising teachers' approaches through the creation of adult learning environments grounded on the principles of dialogic learning. The paper concludes that it is possible to stimulate a gradual transformation of teaching practices through CPD courses promoting self-awareness and critical reflection, which result in a willingness to change towards solidarity and social action.

In the fourth paper the special issue begins to focus on the interface between formal and non-formal settings with Aslam, Adefila and Bagiya examining the ways in which STEM teachers in secondary education perceive the impact of STEM engagement on their own professional development. Aslam et al. argue for the crucial significance of outreach work in STEM where teachers become the interface between the formal context of the school and community-based STEM activity and initiatives. Whilst there are many structural challenges in the ways that outreach work is being brought into formal education, the paper argues that when teachers become the bridge to outreach communities for their learners, this also brings benefits to the learning of the teachers themselves.

In the fifth paper in the special issue, the focus moves beyond formal educational settings to the role of more informal contexts in the education of teachers of STEM. For Fernández Limón, Fernández-Cárdenas and Gómez Galindo, the post-industrial science museum is a vehicle for broadening the perspectives of teachers. This paper reflects the commitment to create new forms of engagement and participation in science museums and science centres underlining the growing recognition that non-formal learning can play a significant role in STEM education

and enable teachers of STEM to come to understand important contemporary debates about science and technology.

Finally, the sixth paper in this issue draws our attention to the societal context and the role of public science in the education of teacher of STEM. Watermeyer and Montgomery focus on the ways in which initiatives around public engagement with science can provide principles for dialogue in teacher education. The paper considers how the engagement of teachers in public science can address issues of teacher knowledge and the paper suggests ways in which principles of good dialogue drawn from models of public engagement with science can be transposed to the teacher training context.

The special issue closes with three practice papers (Gudiño; Salinas Martínez and Quintero Rodríguez; Terrazas-Marín), presenting practical examples from Mexico of some of the ways in which science education for teachers is being approached differently. These practice papers illustrate the importance for teacher education of the link between families and science education, the role of digital technologies in modelling science for teachers and the possibilities offered from outdoor education for transforming teachers' approaches to science education.

The papers in this special issue aim to enable the reader to rethink their perspectives on teacher education for STEM. Here the emphasis is on collaboration and communication and the papers indicate that non-formal learning for teachers is critical and arises in and through social interaction, interaction that enables people to mutually engage in cooperation and co-participation and to become familiar with and understand seemingly technical and complex issues and problems (Falk et al. 2004; Gee 1999; Rennie et al. 2003). Placing the agency for directing STEM within the community could provide a catalyst for promoting STEM careers and genuinely opening opportunities for marginalised groups such as girls, women, lower

socio-economic groups and indigenous or ethnic communities. However, the special issue also underlines the need for formal structures which enable this to happen.

The differences in the way in which globalisation is manifesting itself in the current moment are highlighted by STEM education and illustrated by the case studies presented in this special issue. The examples suggest that by working creatively with local contexts through harnessing the agency of community and non-formal educational settings the claims for the benefits of STEM education may be justified. Partnerships between community settings, teacher educators and science contexts will be a crucial part of this. For these communitarian interactions to succeed it will require a much more coordinated approach between the community, schools, universities, public science and corporations and crucially with government policy on teacher education for STEM.

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